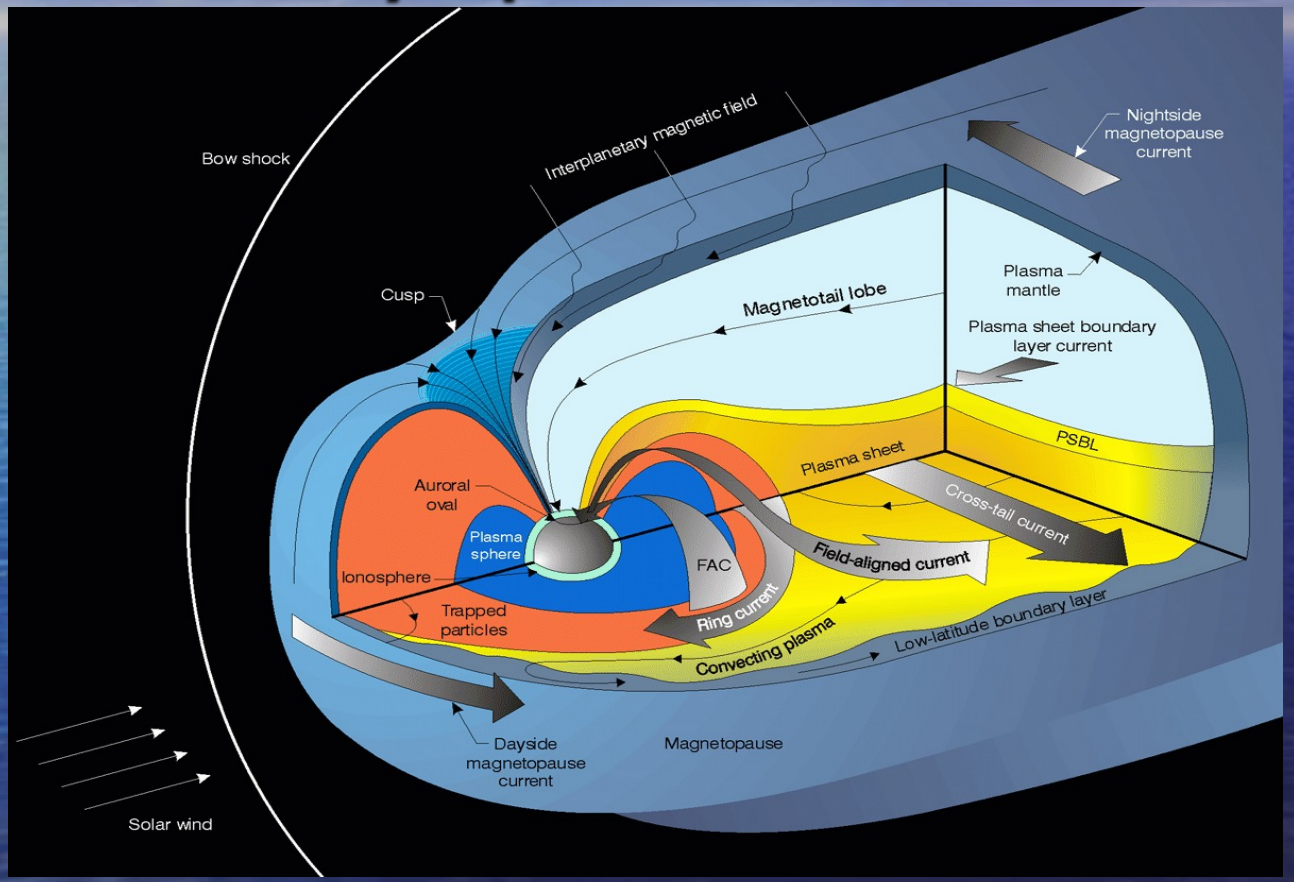
Earth's Magnetosphere
— A very quick introduction



Weichao Tu - LASP of CU-Boulder

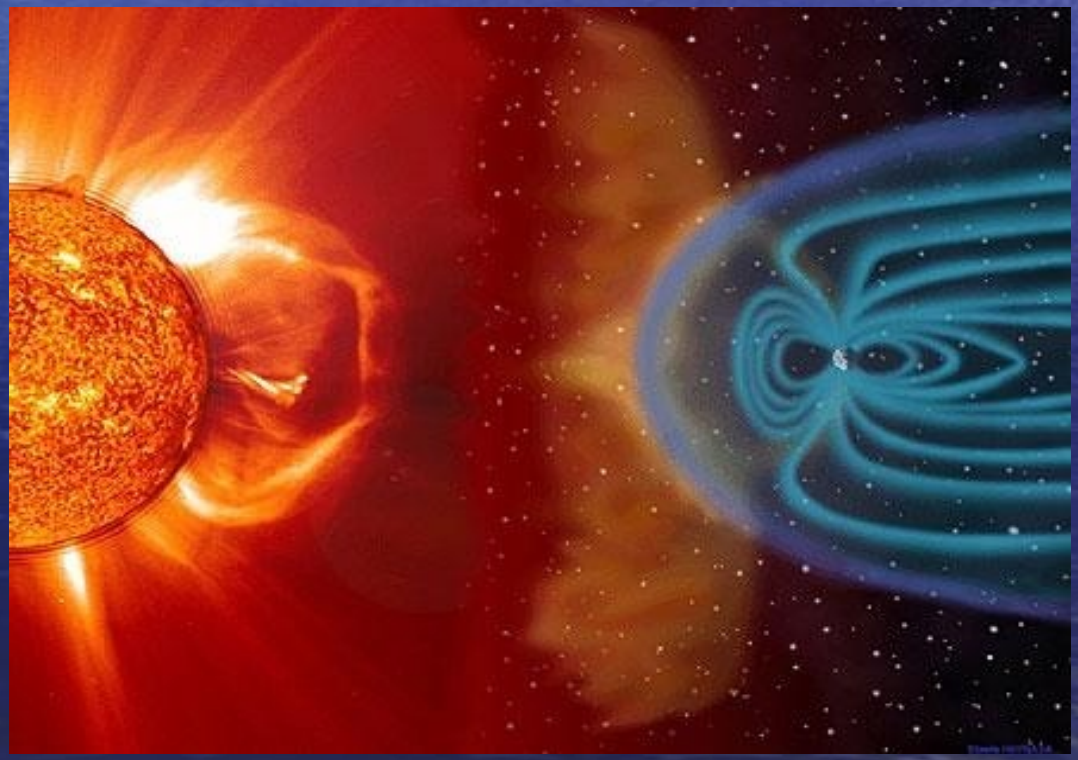
CEDAR-GEM Joint Workshop - Santa Fe, NM - 06/26/2011

Contents: Intro to Magnetosphere

- How is it formed?
- What does it look like?
- What's inside?
- How does it vary?
- Why do we care?

How is it formed?
– Sun-Earth Interaction

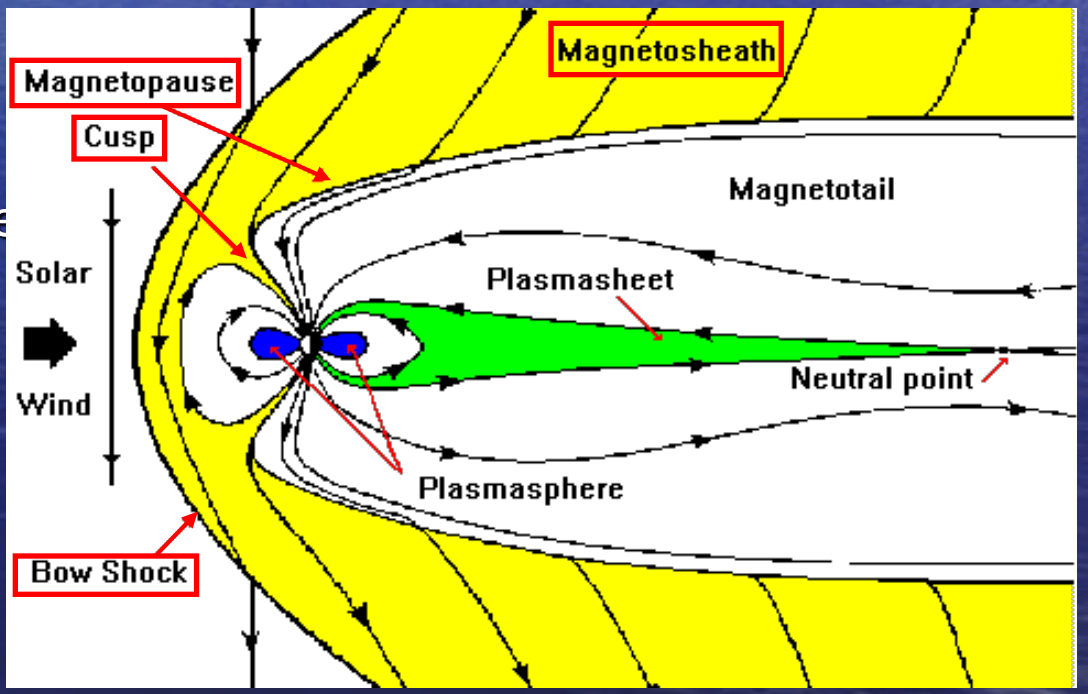
- Earth's internal field
  - a tilted dipole
- Solar wind
  - fast outflow of hot plasma: charged particles
  - carry interplanetary magnetic field (IMF)
- Charged particles in solar wind are swept by Earth's magnetic field, creating a cavity called the Magnetosphere.
  - shelter the surface of Earth from energetic particles of the solar wind



NASA

What does it look like? – The Shape and Boundaries

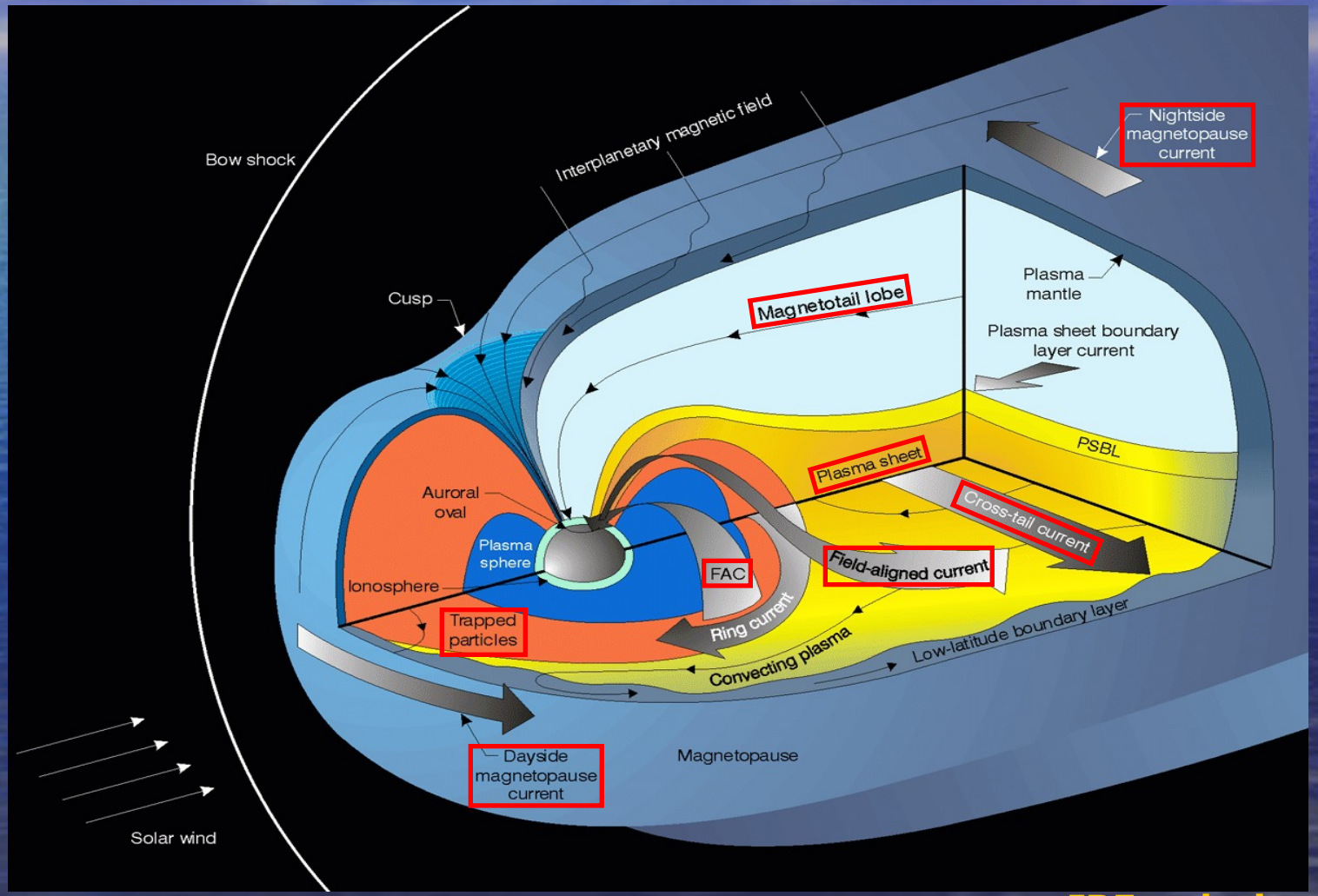
- An oval tear-drop shape
- Magnetopause
  - outer boundary of the magnetosphere
  - compressed in the dayside (10-12 Re) and stretched in the nightside (magnetotail well past 200 Re)
- Bow shock
  - because solar wind is supersonic
- Magnetosheath
- Cusps
- Low-altitude boundary: Ionosphere



NASA

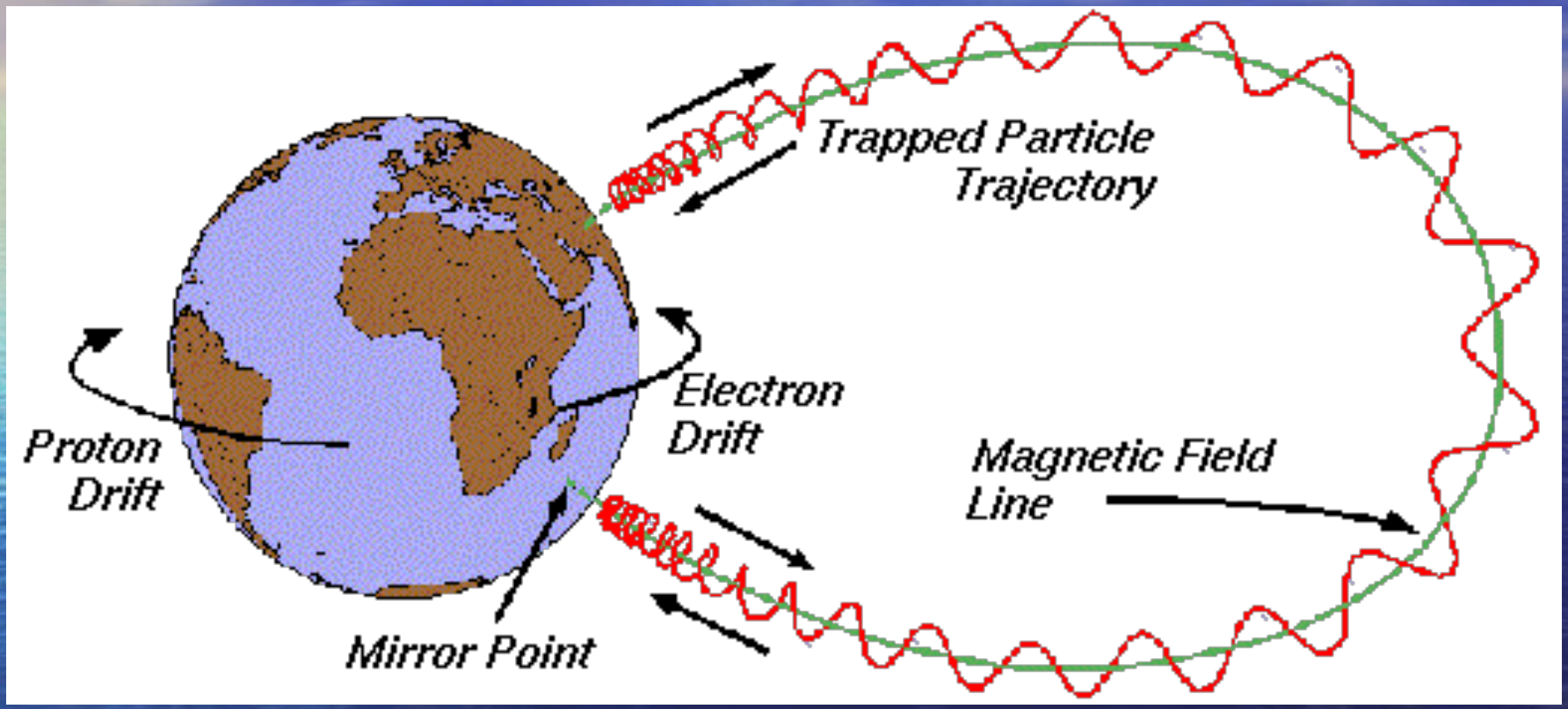
What's inside?
– Currents and Plasma Populations

- Field-Aligned Current
- Magnetopause Current
- Magnetotail
  - Tail currents
  - Plasmasheet
  - Tail Lobes
- Trapped Particles in inner Magnetosphere



IRF web site

What's inside?
– Charged Particle Motions



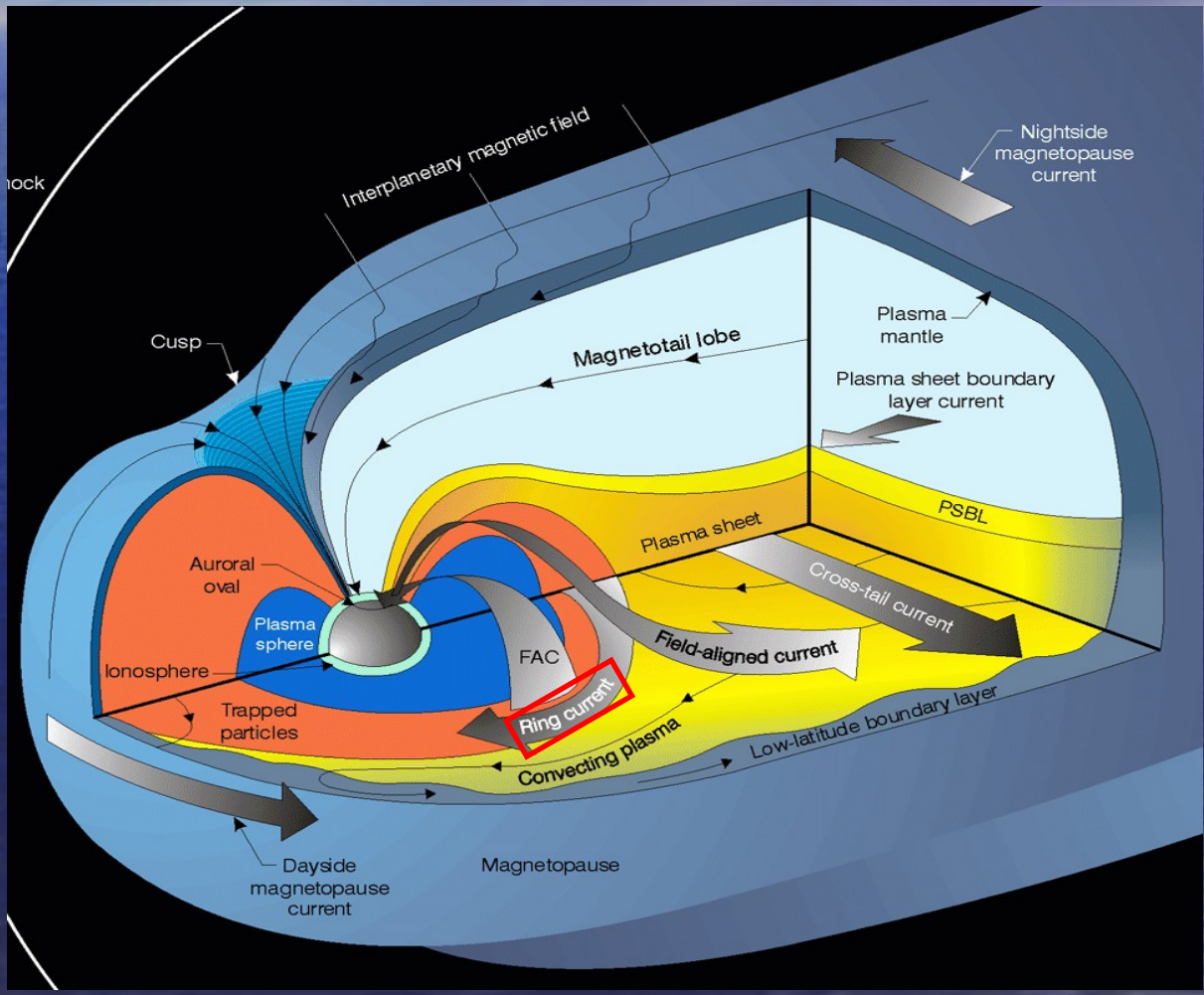
ESA

Characteristic timescales:

- Gyromotion: ~ millisecond
- Bounce motion: ~ 0.1-1.0 sec
- Drift motion: ~ 1-10 minutes

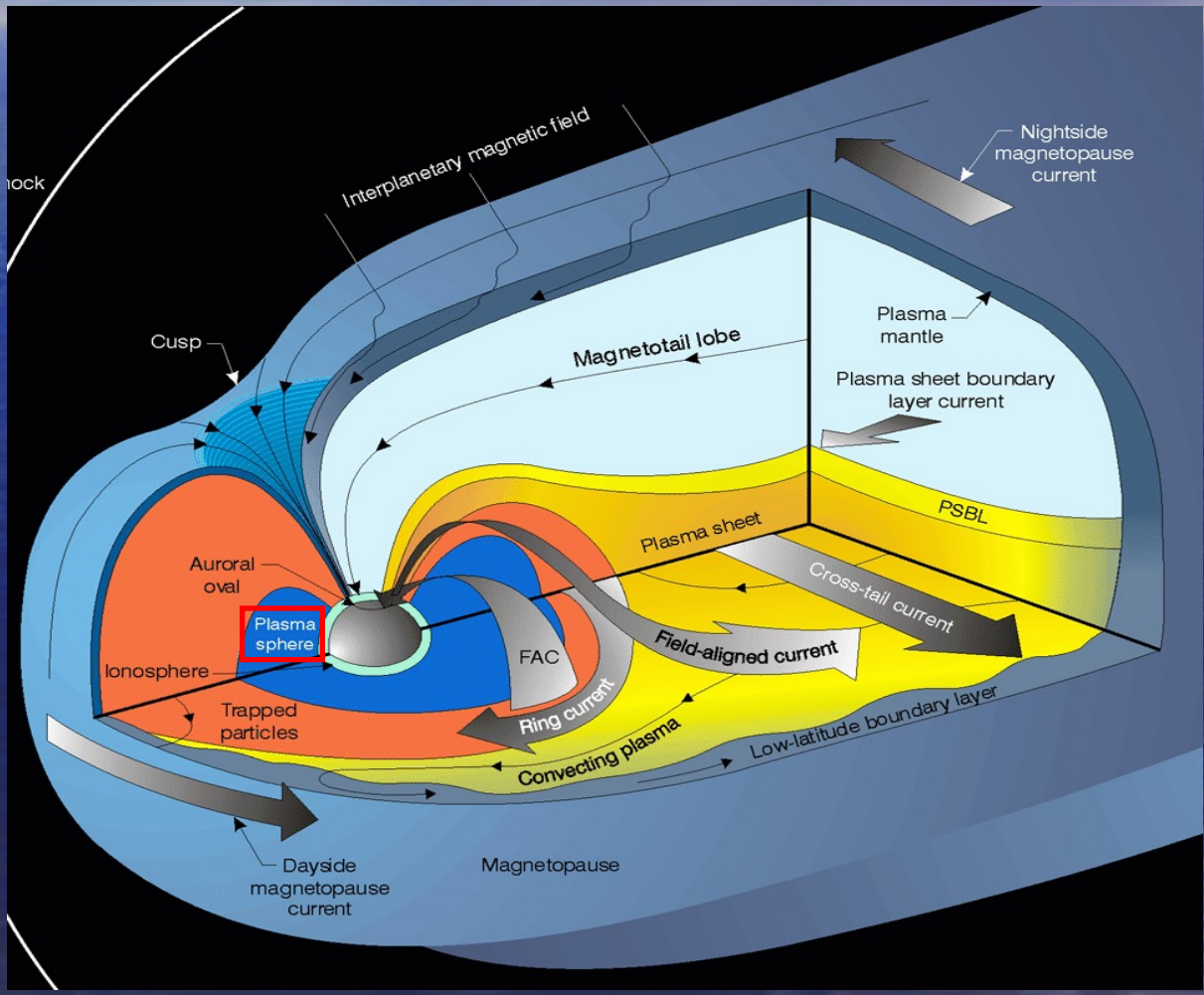
What's inside?
– Inner Magnetosphere

- Ring Current
  - westward current
  - southward magnetic field on ground, decreases the main field strength
  - located at 3-5 Re
  - hot and tenuous plasma
    - 10-200 keV, 1-10s cm^{-3}
  - contains the energy



What's inside?
– Inner Magnetosphere

- Ring Current
  - contains the energy
- Plasmasphere
  - considered an extension of ionosphere that co-rotates with Earth
  - cold and dense plasma
    - <1-10s eV, 100s-1000 cm^{-3}
  - contains the mass
  - sharp outer boundary: plasmapause (3-5 Re)



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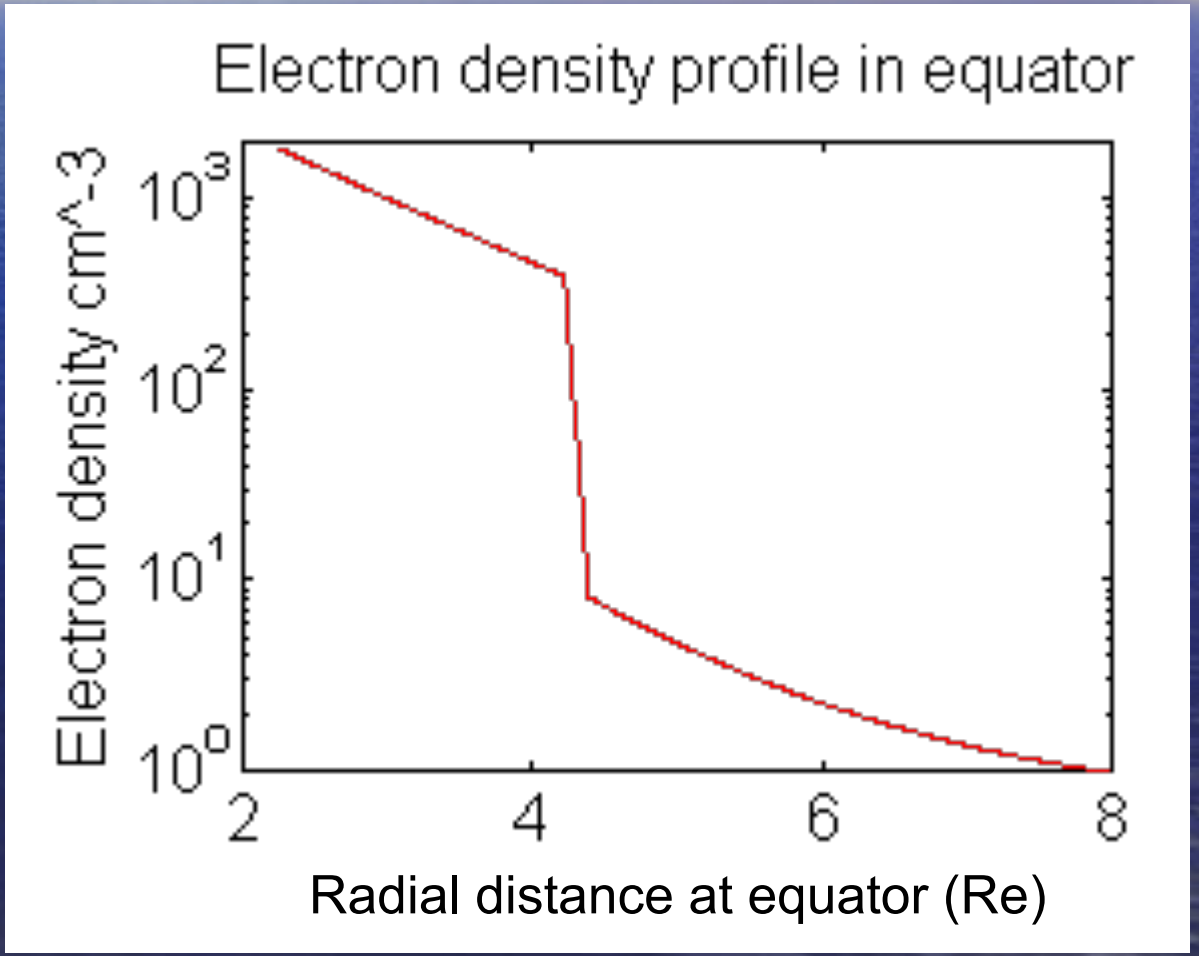

Model from Carpenter and Anderson [1992]

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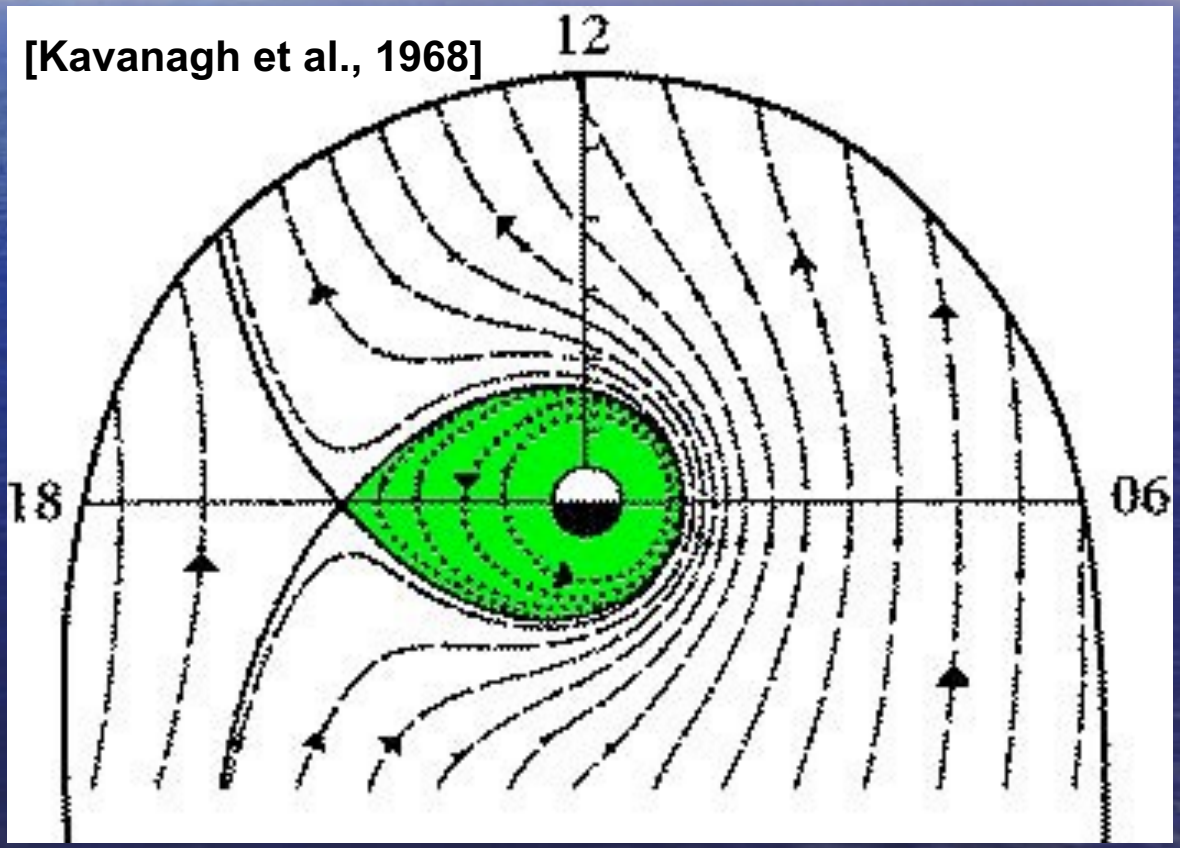
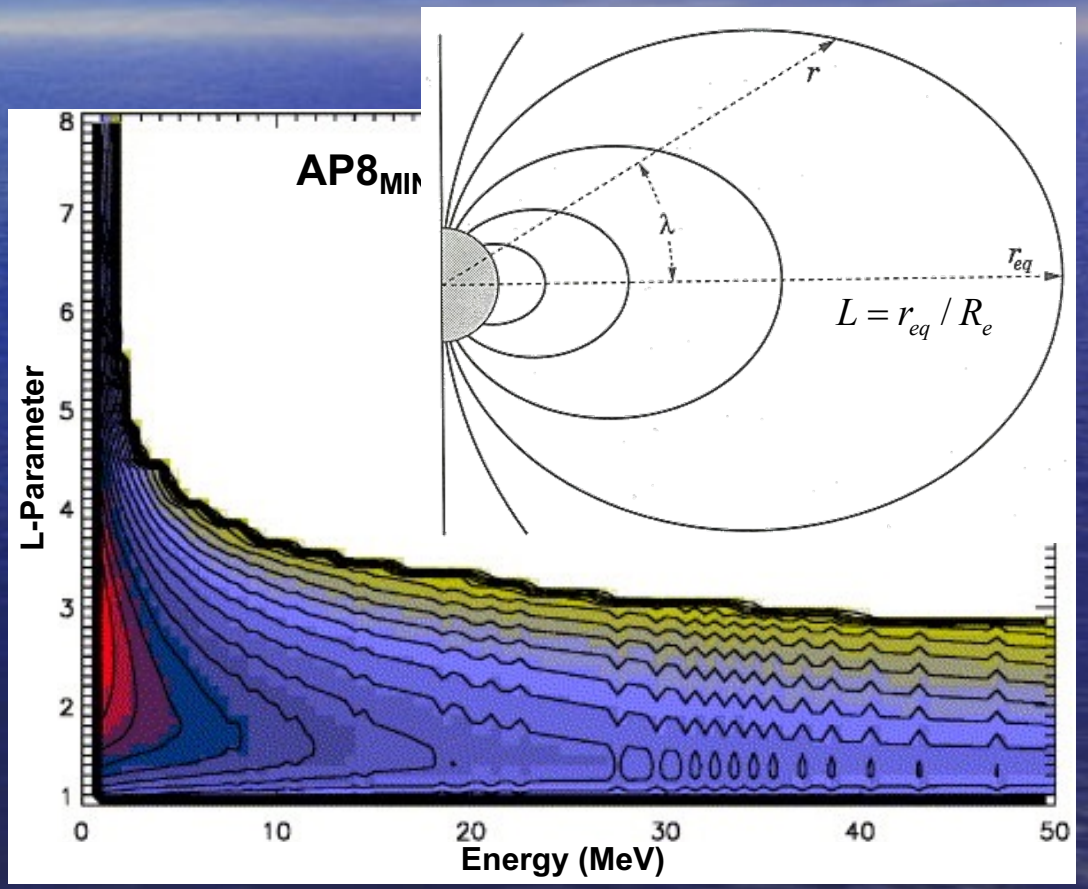


"Separatrix": where co-rotational electric field balances convection electric field

What's inside? – Inner Magnetosphere

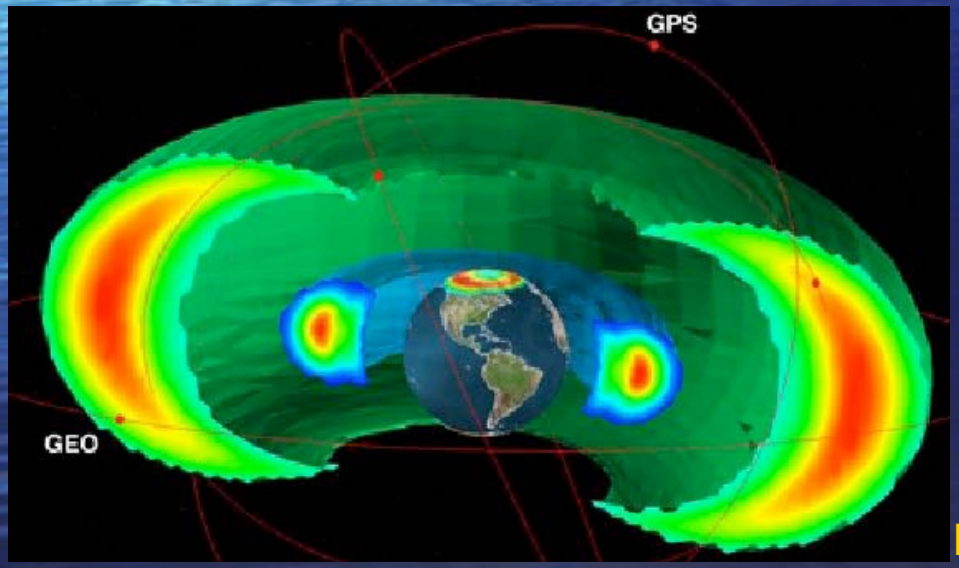
- Ring Current
  - contains the energy
- Plasmasphere
  - contains the mass
- Radiation Belt
  - co-locates with ring current and plasmasphere
  - contains energetic particles
  - proton belt
    - confined to inner regions of magnetosphere, <3 Re
    - energies: >10 MeV
  - electron belt



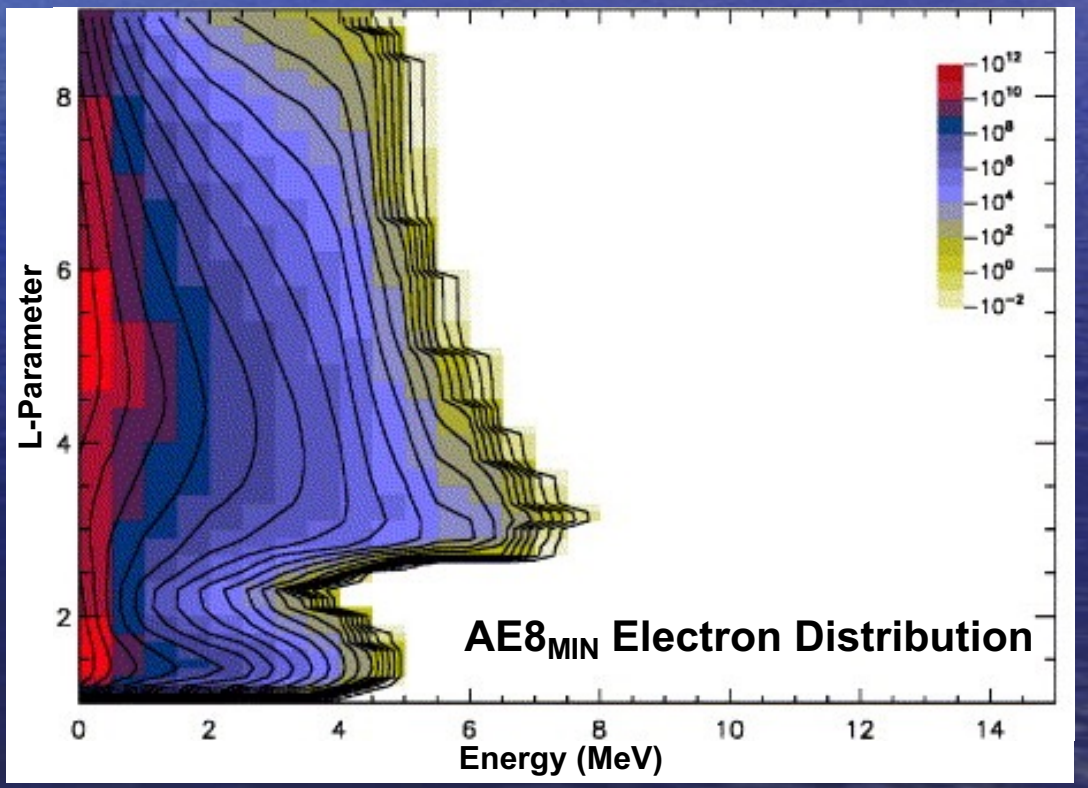
[Elkington et al., 2004]

Electron Radiation Belt

- Two distinct regions
  - Inner Belt: centers ~ 1.5 Re
  - Outer Belt: centers ~ 4-5 Re
  - Slot Region: a region of depleted flux
- Energy: <10 MeV

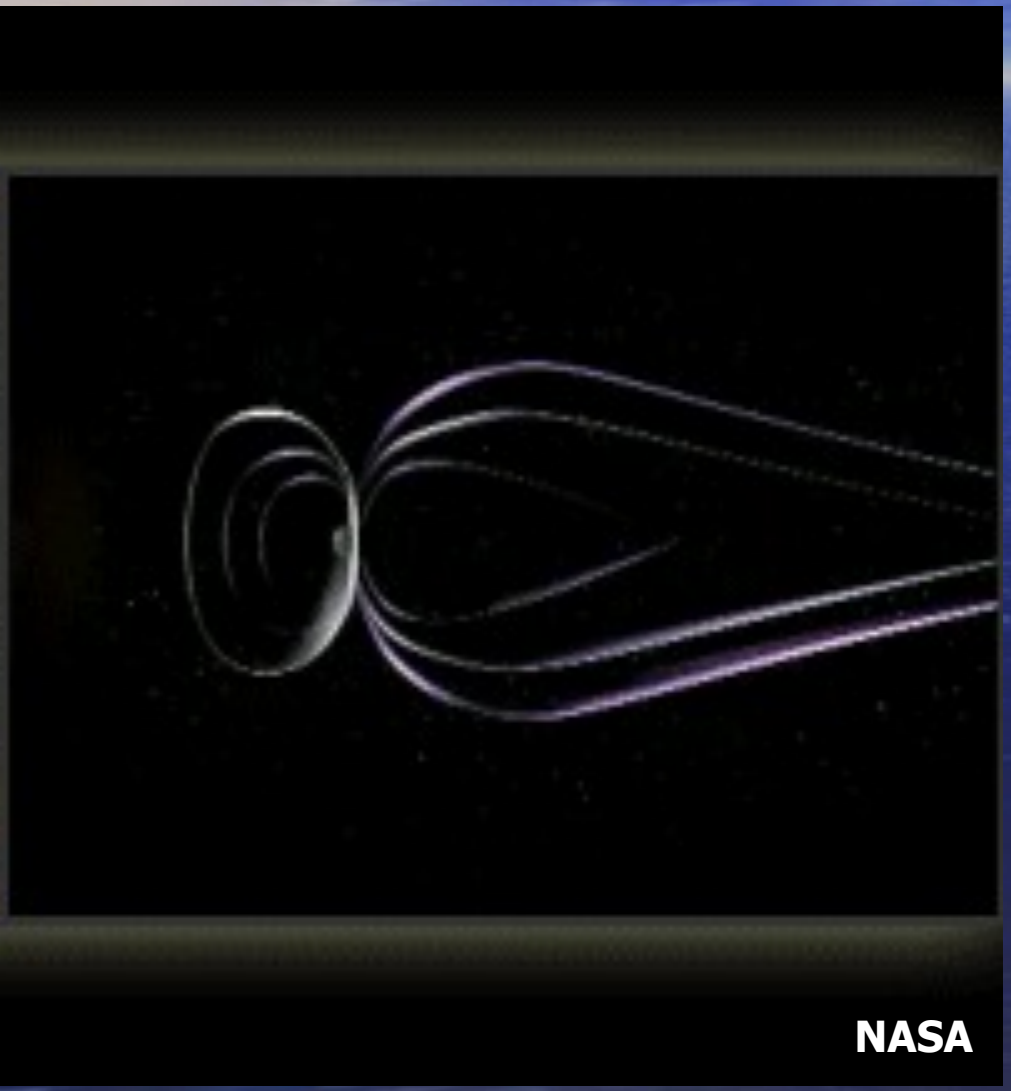


NASA



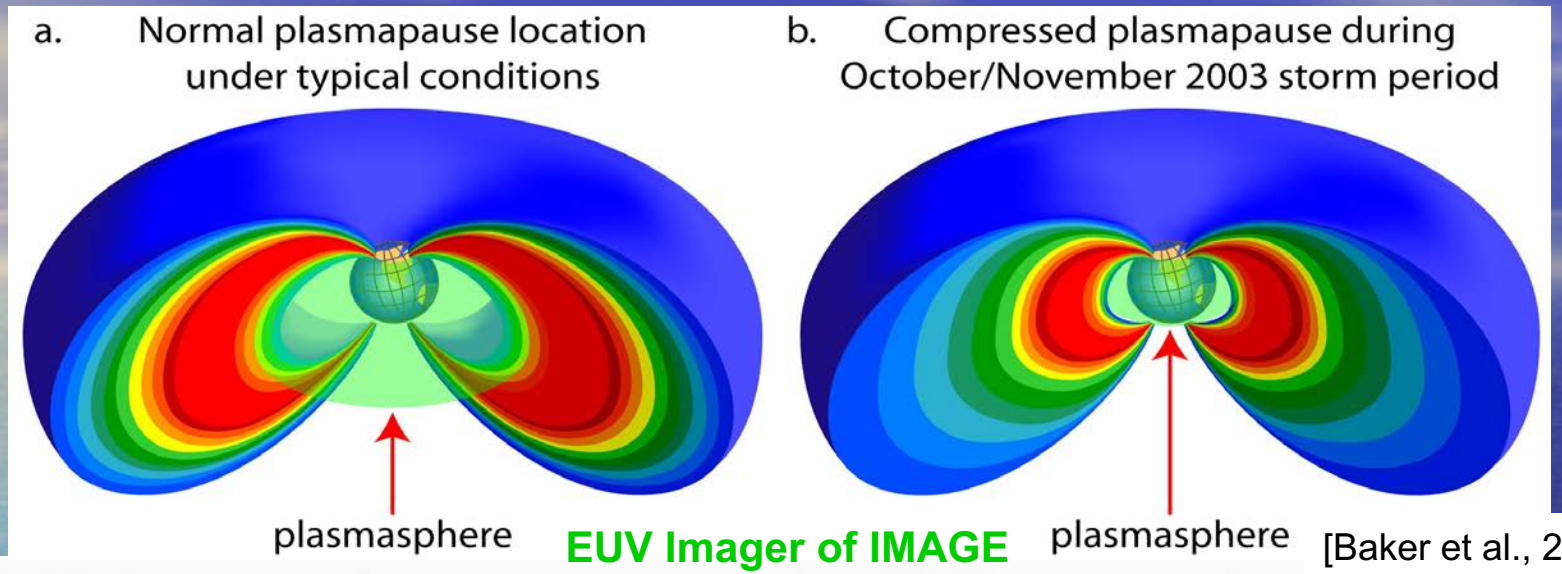
[Elkington et al., 2004]

How does it vary?

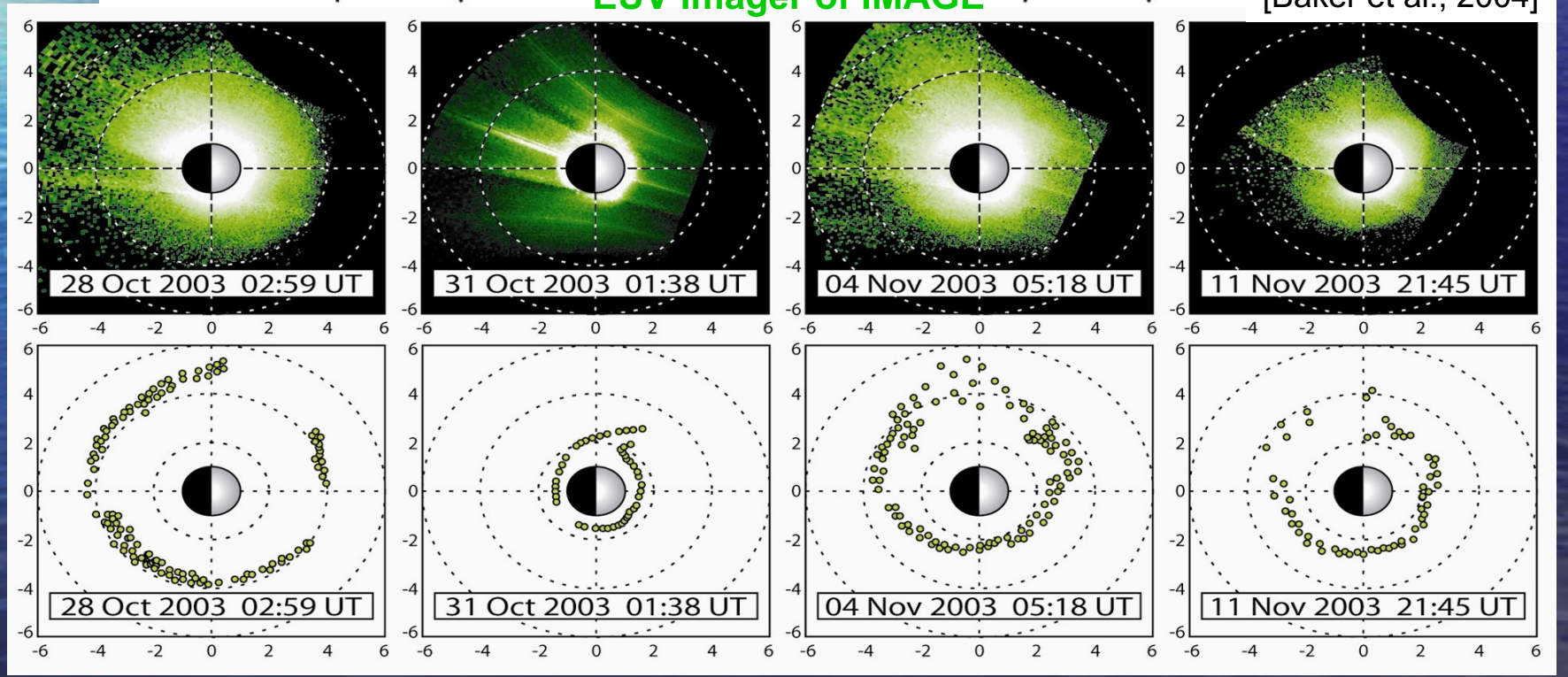


- Magnetospheric Convection
  - Dungey Cycle
  - Feifei Jiang (UCLA)
- Geomagnetic Substorm
  - Aurora
  - Christine Gabrielse (UCLA) and Carl Andersen (UAF)
- Geomagnetic Storm
  - Lauren Blum (U CO)
- Geomagnetic Indices
  - Matina Gkioulidou (UCLA)

Variations of Plasmapause Location



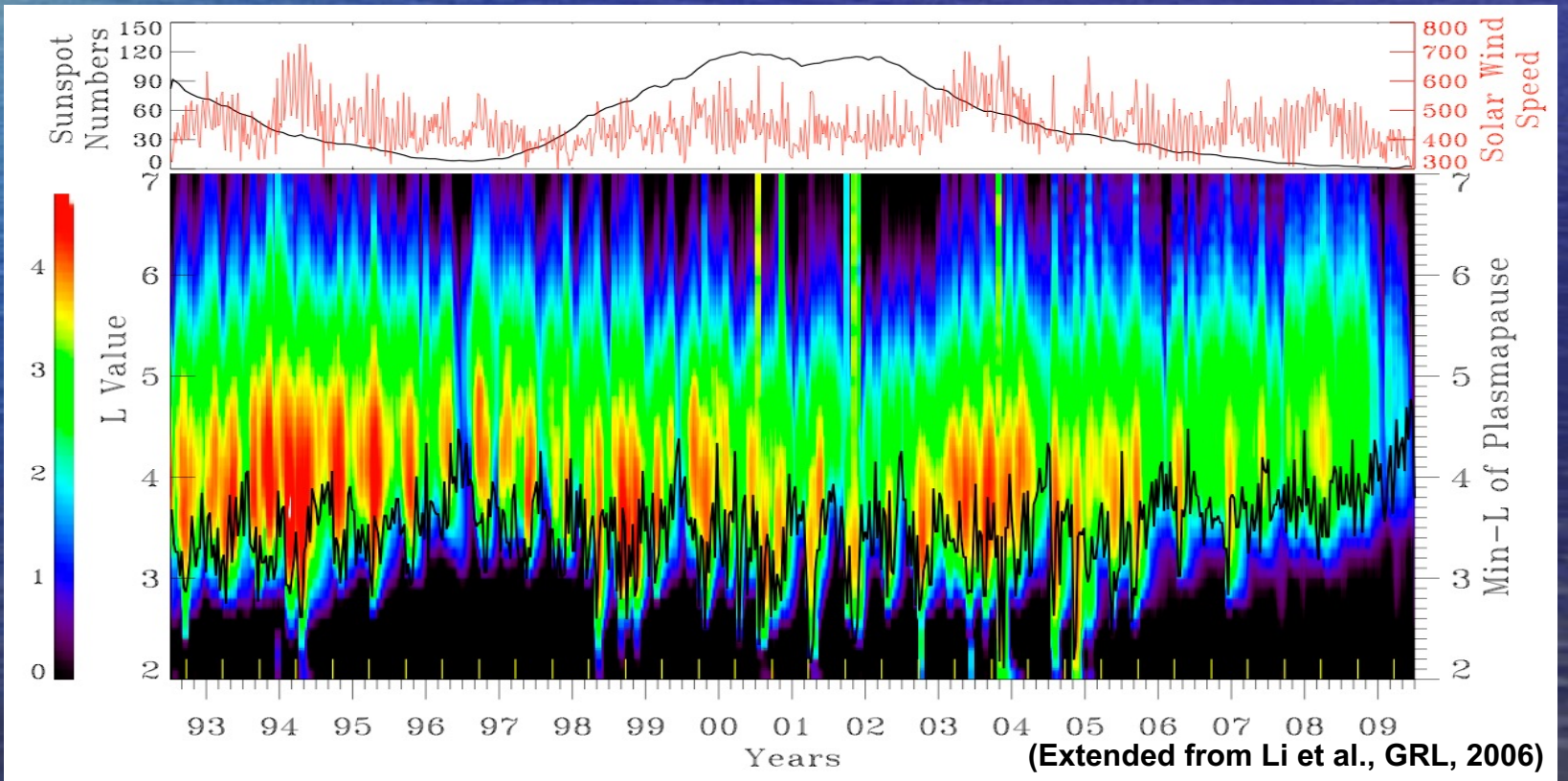
EUV Imager of IMAGE [Baker et al., 2004]



Outer Electron Belt Variations

- Outer electron belt is highly dynamic
  - variable peak flux location; slot region often filled
  - inner boundary correlates with plasmapause location
  - Variations time scales: storm/solar rotation/season/solar cycle

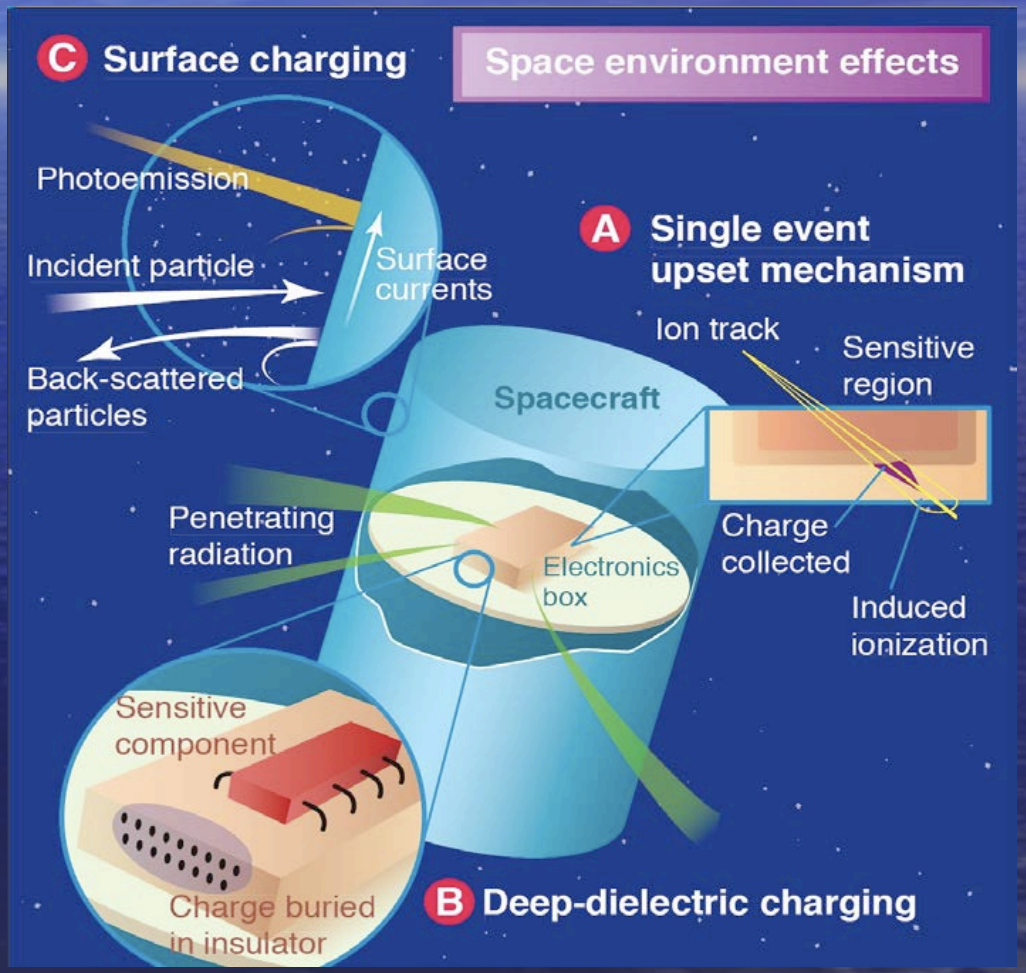
- Color-coded: SAMPEX 2-6 MeV electron flux.
- Black curve: plasmapause location from an empirical model [O'Brien and Moldwin, 2003]



(Extended from Li et al., GRL, 2006)

Why do we care? – Space Weather

- Radiation belt is the environment
  - lots of commercial and military satellites operate
  - major space weather activity occurs
- Energetic particles can lead to, e.g., charge deposition in sensitive electronics on board spacecraft.
- Several satellite 'anomalies' have been associated with variations in the energetic particle environment.
  - e.g., Galaxy 15 failure



NOAA

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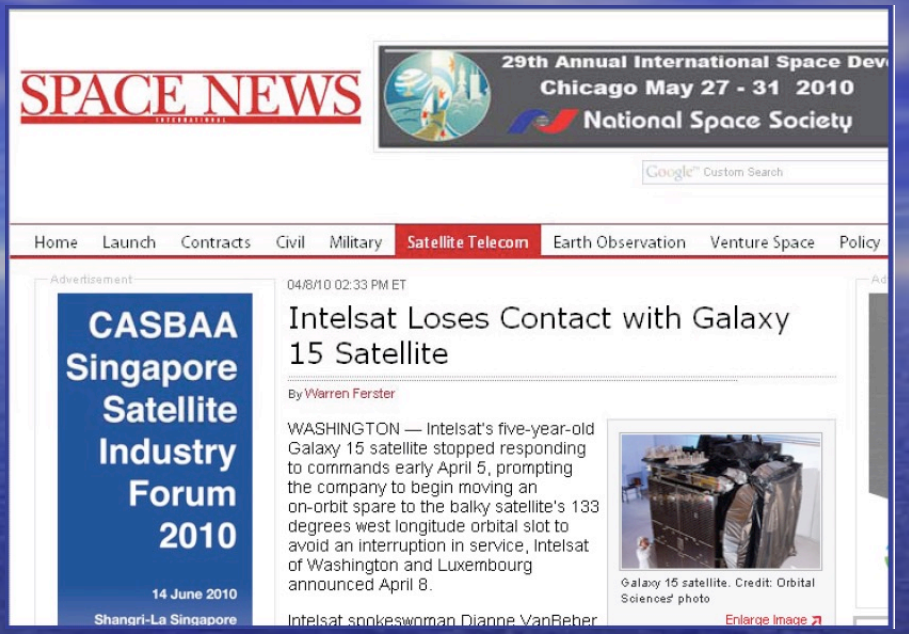

SPACE NEWS

29th Annual International Space Dev
Chicago May 27 - 31 2010
National Space Society

Home Launch Contracts Civil Military Satellite Telecom Earth Observation Venture Space Policy

CASBAA Singapore Satellite Industry Forum 2010
14 June 2010
Shangri-La Singapore

04/8/10 02:33 PM ET

Intelsat Loses Contact with Galaxy 15 Satellite

By Warren Ferster

WASHINGTON — Intelsat's five-year-old Galaxy 15 satellite stopped responding to commands early April 5, prompting the company to begin moving an on-orbit spare to the balky satellite's 133 degrees west longitude orbital slot to avoid an interruption in service, Intelsat of Washington and Luxembourg announced April 8.

Intelsat spokeswoman Dianne VanReher

Galaxy 15 satellite. Credit: Orbital Sciences' photo

Enlarge Image


SPACE NEWS

29th Annual International Space Dev
Chicago May 27 - 31 2010
National Space Society

Home Launch Contracts Civil Military Satellite Telecom Earth Observation Venture Space Policy

CASBAA Singapore Satellite Industry Forum 2010
14 June 2010
Shangri-La Singapore

04/20/10 02:05 PM ET

Orbital Blames Galaxy 15 Failure on Solar Storm

By Peter B. de Selding

PARIS — The in-orbit failure of the Orbital Sciences-built Intelsat Galaxy 15 telecommunications satellite April 5 was likely caused by unusually violent solar activity that week that damaged the spacecraft's ability to communicate with ground controllers, Orbital officials said April 20.

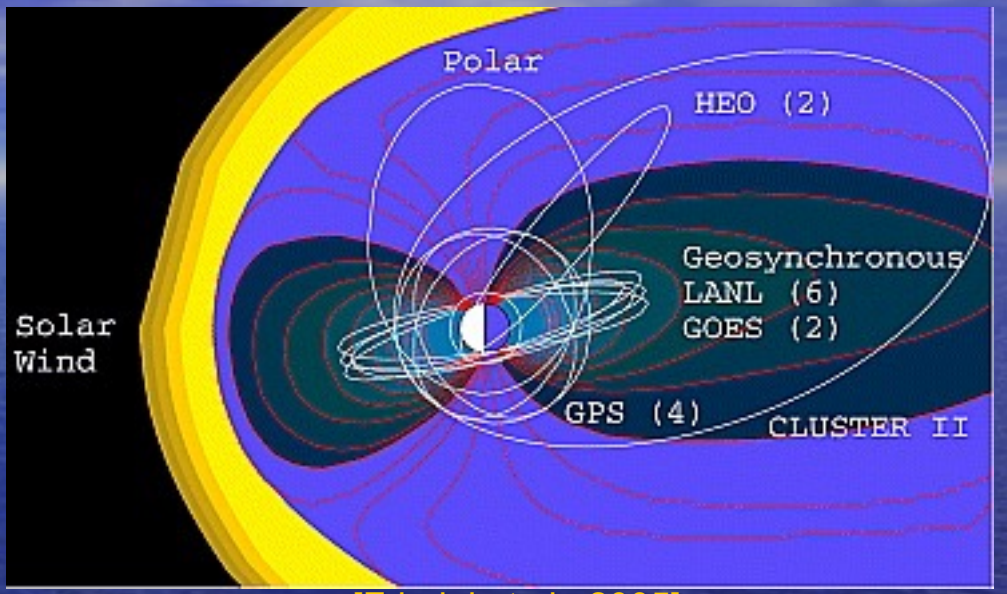
Similar events have occurred, if less severely, on other Orbital spacecraft

Galaxy 15 satellite. Credit: Orbital Sciences' photo

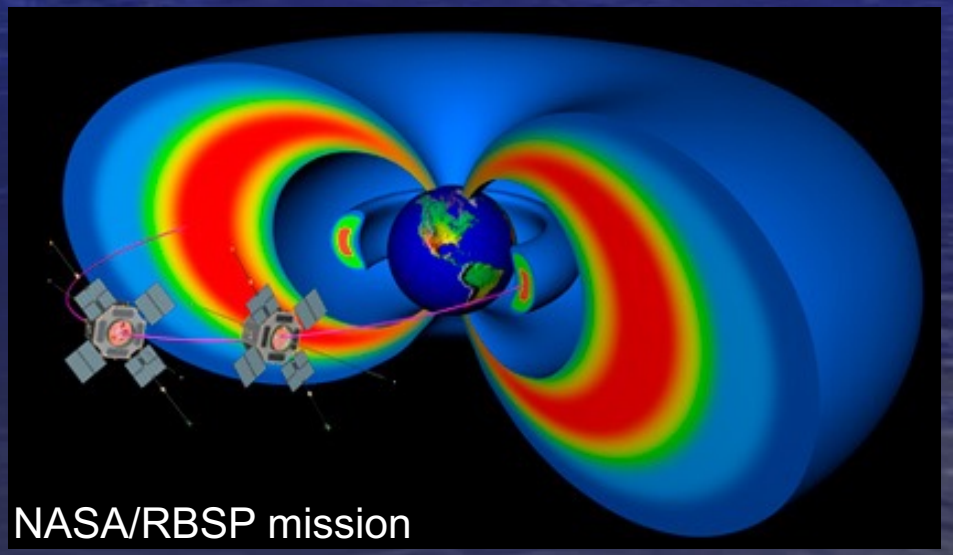
Enlarge Image

Observations and Models

- More and better observations and models are needed for understanding magnetosphere dynamics.
- Observations
  - Low Earth Orbit (SAMPEX, DMSP)
  - Geosynchronous Orbit (GOES, LANL)
  - Eccentric Orbit (IMAGE, CLUSTER, THEMIS, RBSP)
  - CubeSats
    - Alex Crew (UNH)
- GEM Models
  - Matt Gilson (UNH)



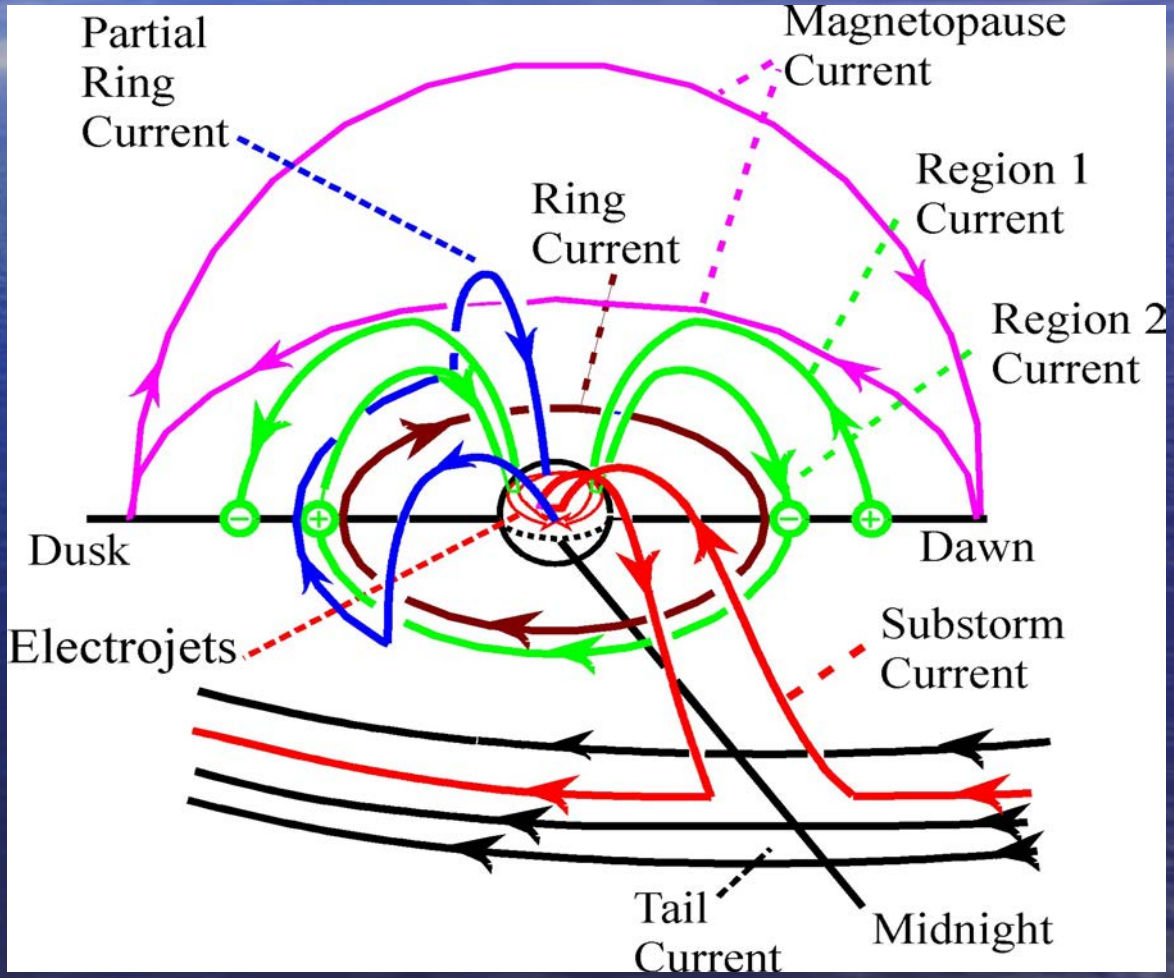
[Friedel et al., 2005]



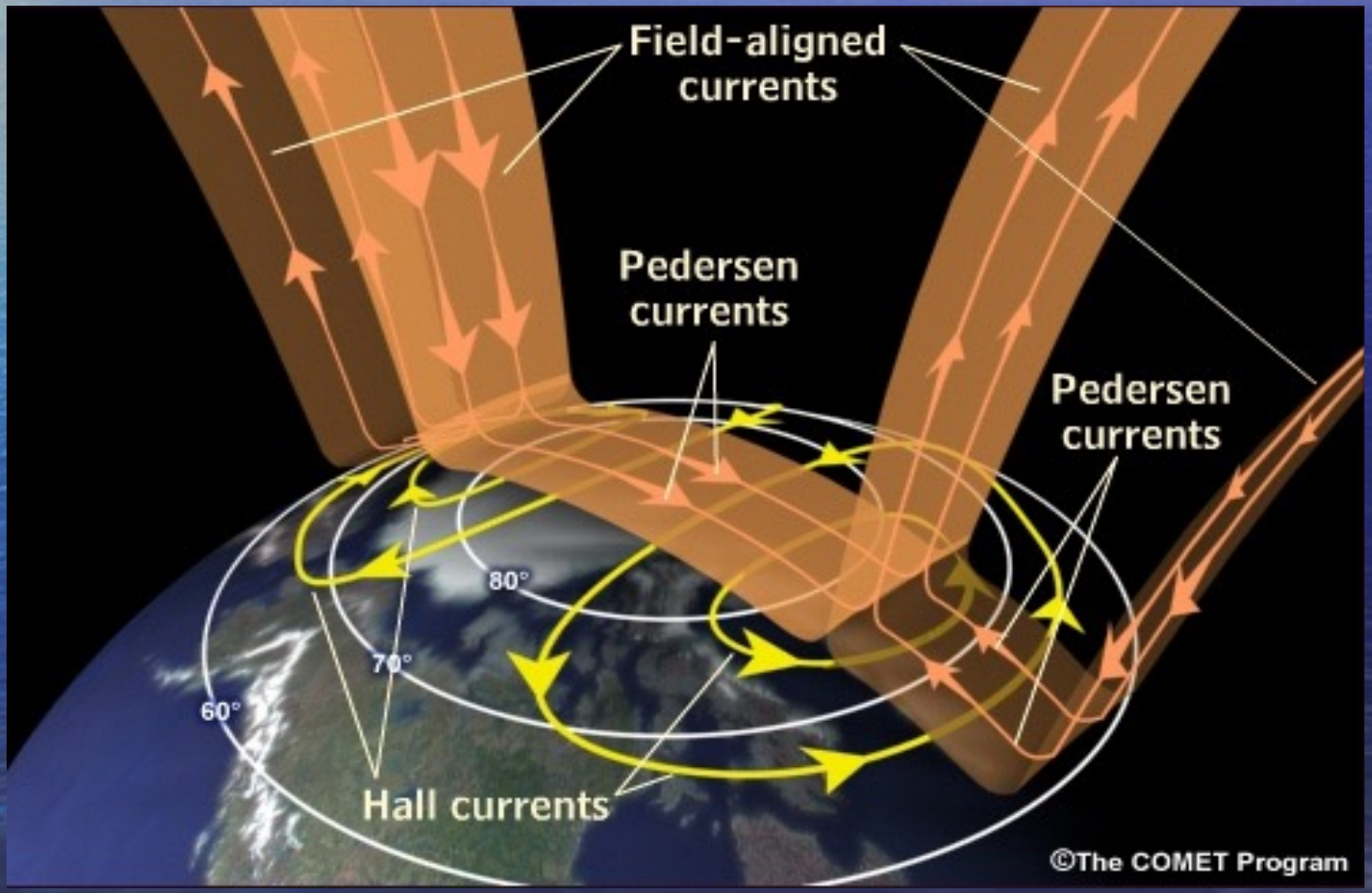
Thank you!

Current Systems in the Magnetosphere

- There are many current systems in the magnetosphere
- Some flow perpendicular to the field, others along the field
- The diagram schematically shows the following:
  - Magnetopause current
  - Tail current
  - Ring current
  - Region 1 current
  - Region 2 current
  - Substorm current wedge
  - Partial ring current

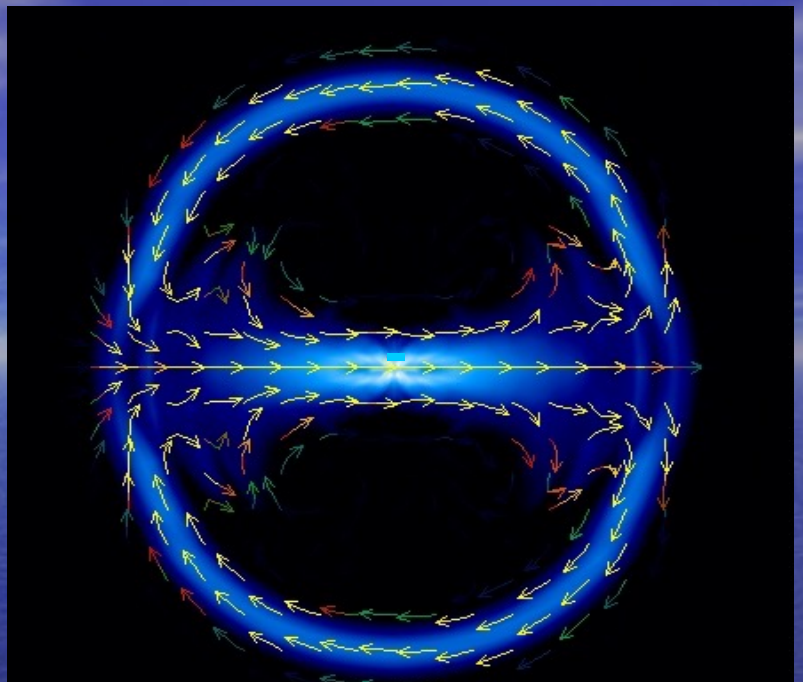


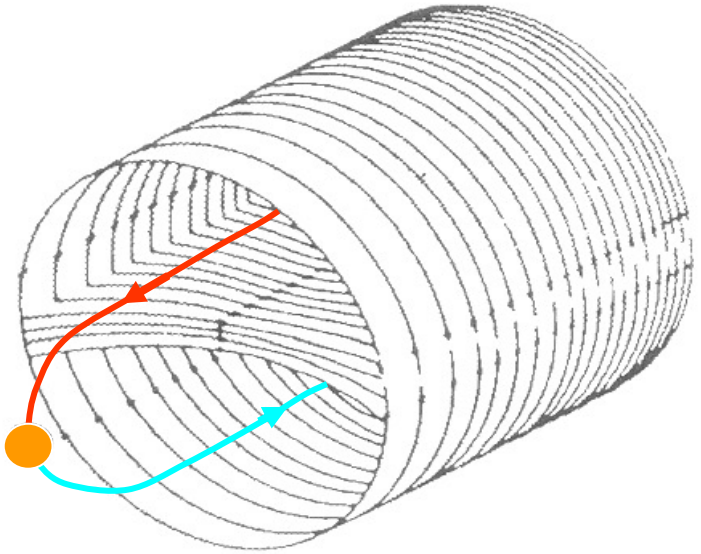
Perspective View of R-1 & R-2 Currents



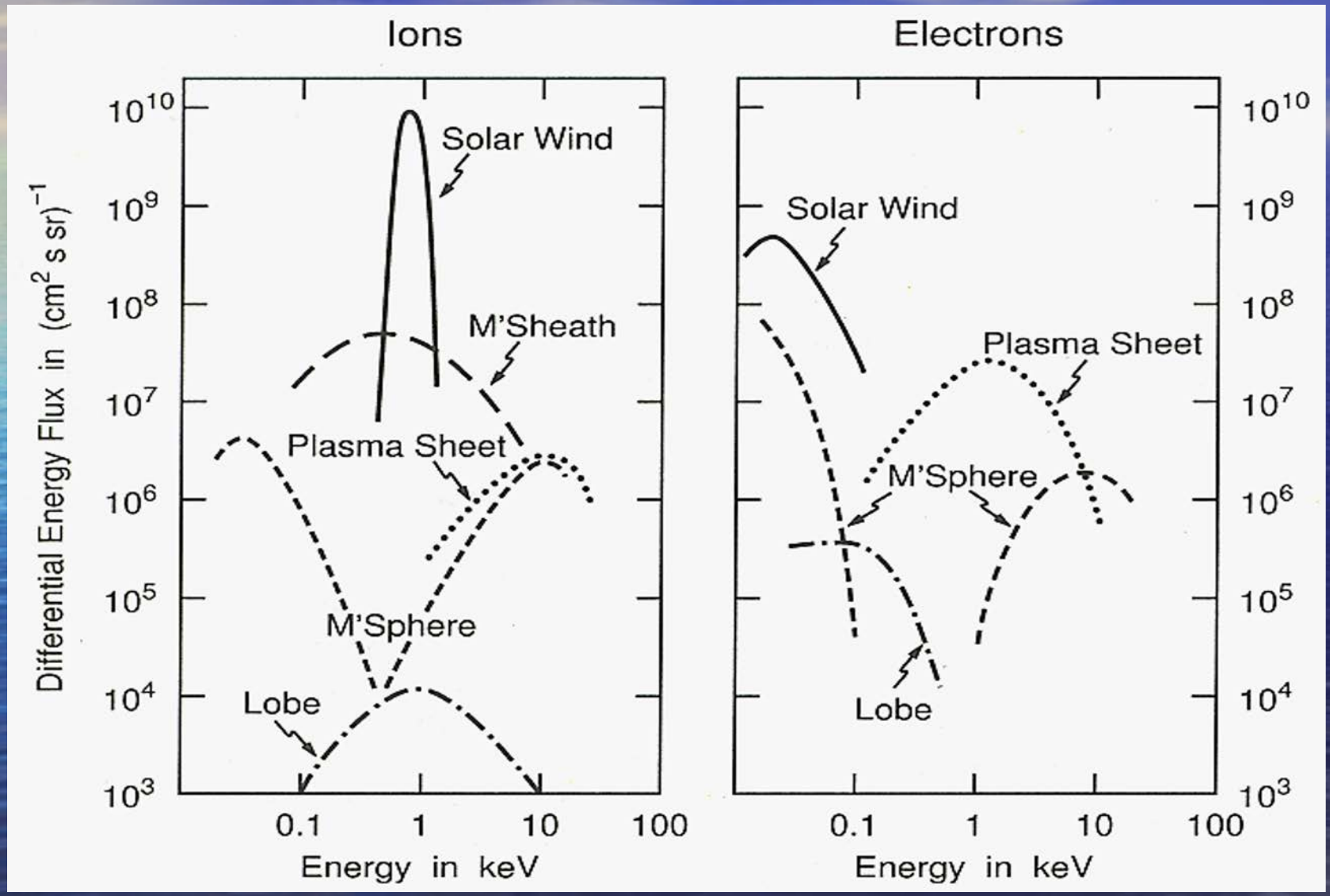
The Tail Current

- The tail current is produced by two solenoids downstream of Earth with current flowing in opposite sense in each solenoid
- The effect is a fringing field in the vicinity of the Earth that reduces the horizontal component
- The effect is stronger on night and evening side creating an asymmetry in the surface field

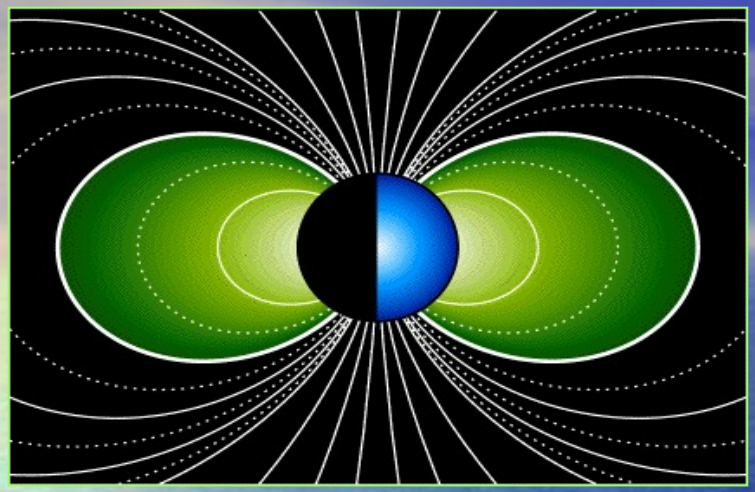


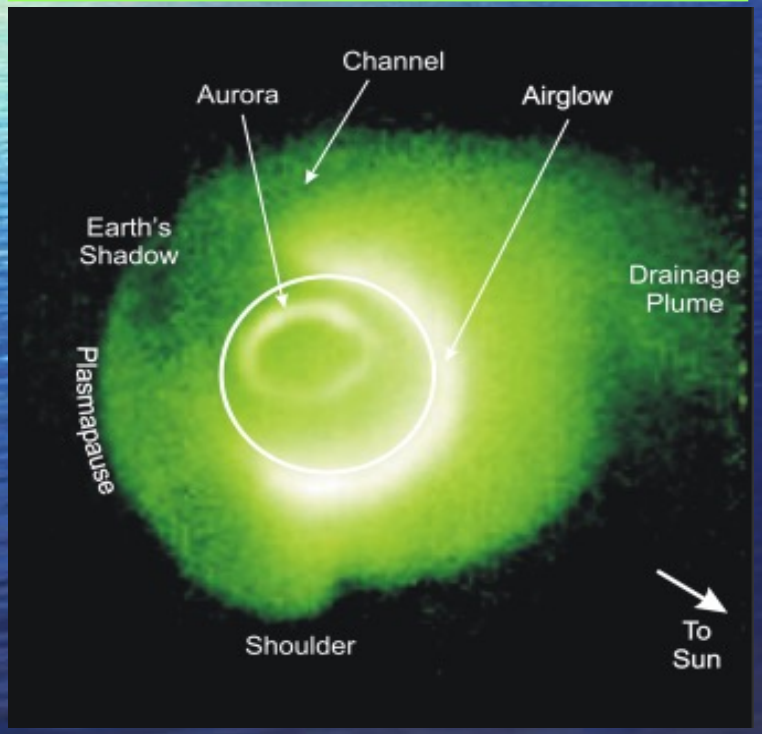


Particle fluxes in near Earth space



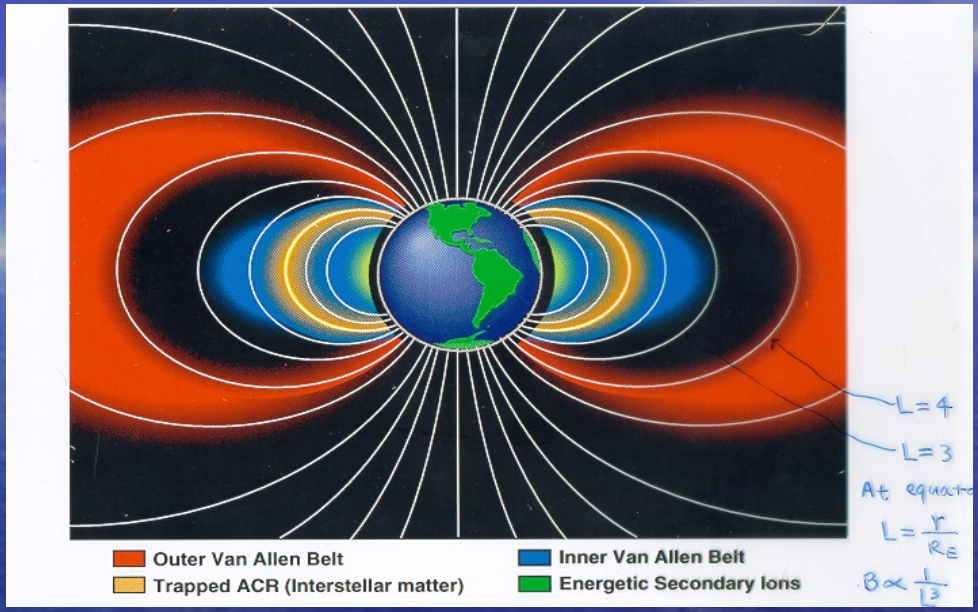
plasmasphere





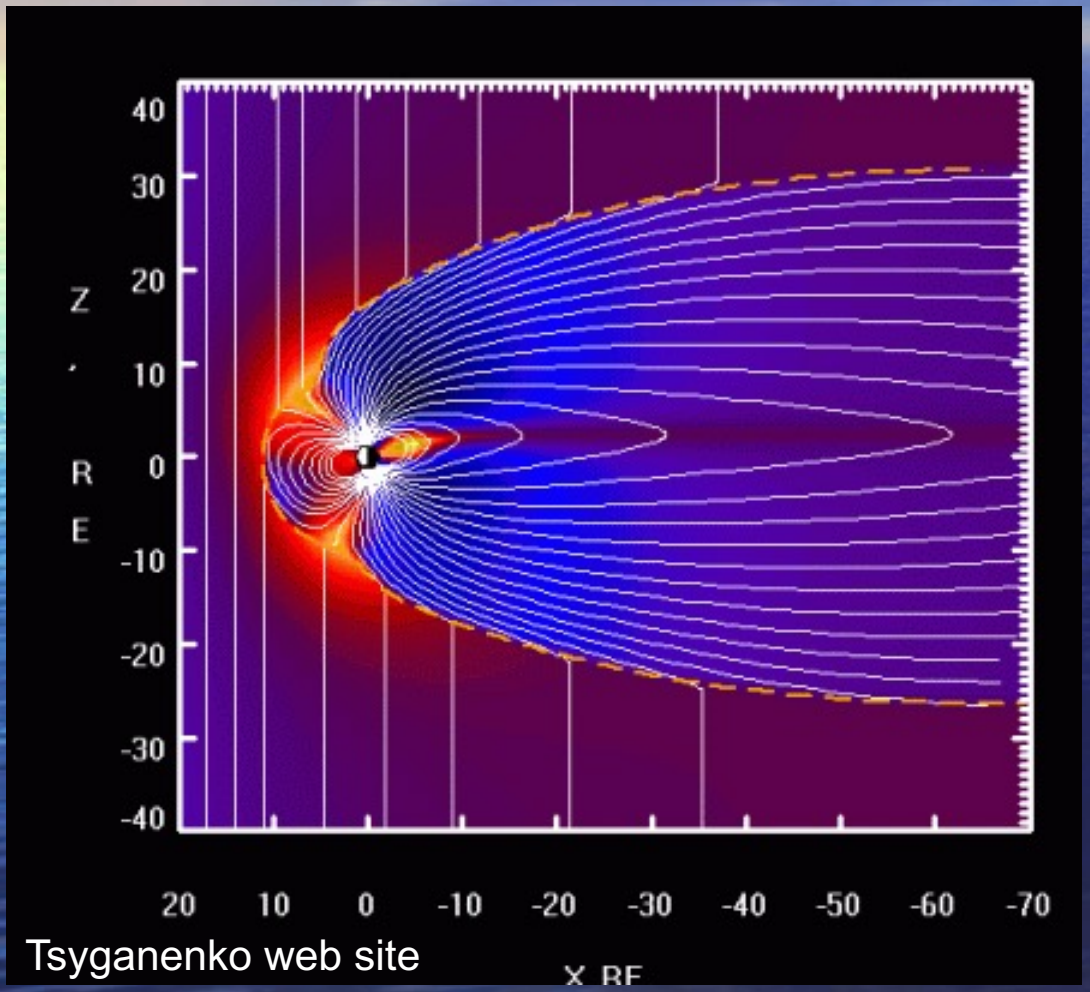
(Sandel et al., 2003)

Radiation Belts



(from the Extreme Ultraviolet Imager of IMAGE)

How does it vary?

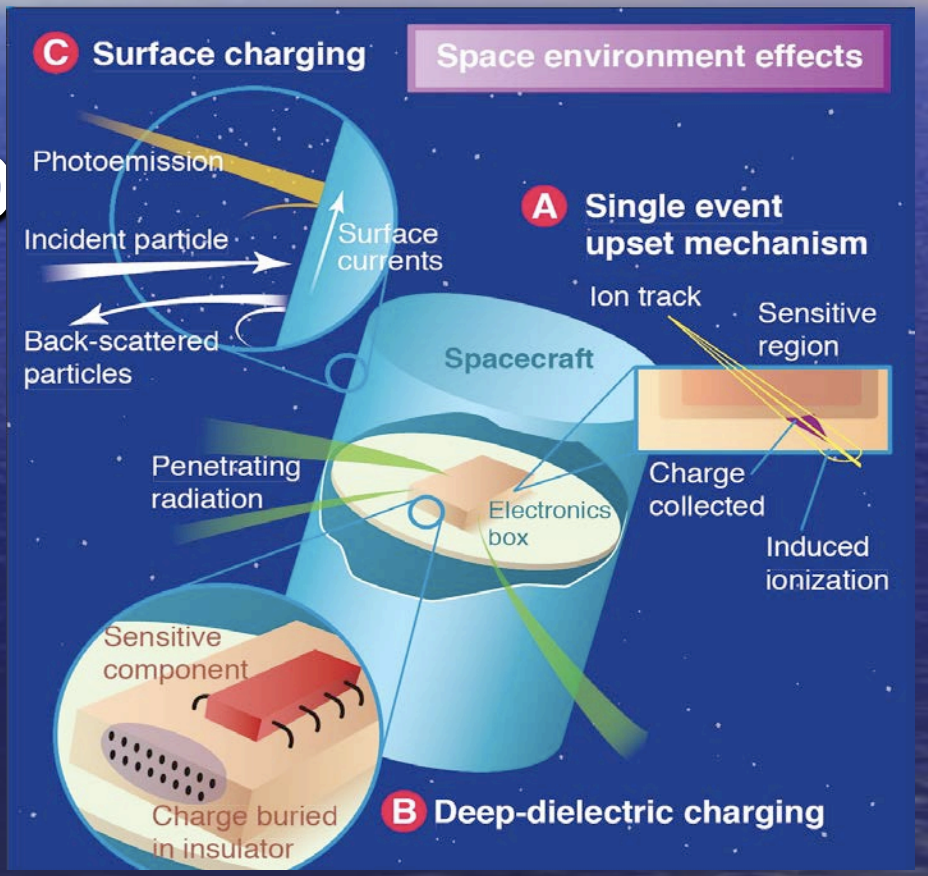


Tsyganenko web site

- Magnetospheric Convection
  - Dungey Cycle

Radiation effects o

- Single event upset (SEU)
  - change of state caused by energetic ions striking a sensitive node in a micro-electronic device
- Deep-dielectric charging
  - Energetic electrons penetrate a particular component and build up charge
  - Eventual discharge like "mini-lightning strike"
- Surface charging
  - Lower energy electrons can build up charge on spacecraft surface
  - Resulting discharge can scramble satellite signals



D. N. Baker, Science 297, 1486, 2002